

UCSD/PTH-94-04
April 1994

An Alternative Method of Extracting V_{bu} from Semi-leptonic B Decay

Jin Dai ¹

Department of Physics 0319, University of California, San Diego
9500 Gilman Dr. La Jolla, CA, 92093-0319

ABSTRACT

We propose a new method of extracting V_{bu} from measurements of Semi-leptonic B decay which has much less theoretical uncertainties than conventional methods.

¹E-mail address: dai@higgs.ucsd.edu

The Kobayashi-Maskawa matrix element V_{bu} is among the least known standard model parameters. Knowing its exact value is very important for understanding standard model CP violation and radiative corrections. However, extracting V_{bu} from experiment is difficult due to hadronic physics uncertainties.

At the present time, V_{bu} is measured in charmless semileptonic B decays, especially from the inclusive lepton spectrum. The advantage of using inclusive decay modes is that it can be calculated using the parton model approach[1], and nonperturbative effects can be systematically analysed using heavy quark theory[2]. However, in experiment, there is an overwhelming background from the decay process

$$b \rightarrow c + l + \nu.$$

The only way to get a clean measurement is to concentrate on the kinematic region where b to c decay is not allowed. In charmless B decay, the lepton energy E_l is kinematically allowed up to $m_B/2$, and in b to charm decay, E_l is allowed up to $m_B - m_D^2/2m_B$. That leaves available only about 330MeV of energy near the end point of lepton spectrum.

Unfortunately, it is the endpoint spectrum that is least known theoretically. In the parton model, the maximum E_l allowed is $m_b/2$, where m_b is the b quark mass instead of the B meson mass. For $m_b = 4.8\text{GeV}$, this is 240MeV below the kinematic maximum. QCD radiative corrections have been calculated[3] and contain large logs near the parton model maximum. Beyond the parton model maximum, there is no systematic way of calculating the lepton spectrum, and different models lead to very different results[4].

Instead of thinking of improving the theoretical estimate of the end point lepton spectrum, we propose an alternative way to get a more precise V_{bu} : Measure quantities which can be calculated better theoretically. In this paper, we will assume that the neutrino momentum can be measured as well as the lepton momentum in semileptonic B decays. This is not unrealistic at electron-positron machines(e.g. CLEO), where missing momentum and missing energy can be measured and the neutrino mass shell condition can be used to reduce backgrounds from particles leaking out of beam pipes. We will show there is a better way to extract V_{bu} which has few theoretical uncertainties.

First, with the neutrino momentum known, it is much easier to separate the two quark processes $b \rightarrow cl\nu$ and $b \rightarrow ul\nu$ in semileptonic B decay

$$B \rightarrow l + \nu + X. \tag{1}$$

The key observation is that if the underlying quark decay is b to c , then

$$M_X^2 > m_D^2. \tag{2}$$

For b to u decay, at the quark level, the process is dominated by one outgoing u quark or one u quark and one gluon going almost parallel. In either case,

$$M_X^2 \approx 0. \tag{3}$$

When the momenta of the B meson, the lepton and the neutrino are all known, the 4-momentum of X is determined. Therefore we propose the following cut which corresponds

to excluding the kinematic region defined by equation (2):

$$E_l + E_\nu > \frac{m_B^2 - m_D^2 + 2E_l E_\nu (1 - \cos \theta)}{2m_B}. \quad (4)$$

where E_l and E_ν are lepton and neutrino energies in the rest frame of the B meson and θ is the angle between the directions of the lepton and the neutrino. This cut will exclude the b to c decay background and keep most of the b to u decay events.

Based on the matrix elements by Ali and Pietarinen[3], we did a numerical calculation of lepton and neutrino distribution including QCD radiative corrections. It turns out that about 95% of the $b \rightarrow u$ events will survive the cut mentioned above. Without knowing θ , you can still exclude b to c decay kinematically by using the cut obtained by setting $\cos \theta = -1$ in equation (4), but only around 40% of events are left. Without any knowledge of the neutrino, as is the way that current experiments are done, one can use only a small portion of the events. (For reasons explained above, theory can not predict the exact amount of events near the lepton end point.) Background from charm quark leptonic decay can be excluded by cutting on a high invariant mass of the lepton-neutrino pair, if it turns out to be statistically favorable.

The parton model differential cross section $d\sigma/dE_l dE_\nu$ has large logs when E_l or E_ν approach $m_b/2$, but now we don't have to focus on the edge of the kinematically allowed region where the theory has large uncertainties. Instead, we can make the cut

$$E_l, E_\nu < \frac{m_B}{2} - \delta \quad (5)$$

where δ should be a few hundred MeV. We will get a partial decay rate which is almost free of theoretical uncertainty, and be able to compare to experiment to extract V_{bu} ! The remaining uncertainty comes from uncertainty in m_b , which may be determined by studying the shape of the b to c semi-leptonic decay spectrum.

It is up to experimental physicists to decide whether the neutrino momentum can be reconstructed with a reasonable efficiency, but if it can be done, we can have a much better measurement of V_{bu} . Having good detector coverage will be important on future B factories for using this method.

After this work was completed, we received [5], in which the authors suggest measuring the total final state hadron energy. This corresponds to making the following cut

$$E_l + E_\nu > m_B - m_D$$

in which 25% of the events (according to our calculation) near the end point will survive. Of course, if one can identify each hadronic track of the B decay, one can measure m_X^2 directly.

Acknowledgements

The Author would like to thank A. Manohar for extensive discussion, H. Paar for discussion of CLEO experiment, and M. Luke for useful conversation. Work was supported by DOE under grant DE-FG03-90ER40546.

References

- [1] J. Chay, H. Georgi and B. Grinstein, Phys. Lett. B247, 399(1990).
- [2] I.I. Bigi, M. Shifman, N.G. Uraltsev and A.I. Vainshtein, Phys. Rev. Lett. 71, 496(1993).
A. Manohar and M.B. Wise, Phys. Rev D49, 1310(1994).
- [3] A. Ali and E. Pietarinen, Nucl. Phys. B154, 519(1979).
N. Cabibbo, G. Corbo and L. Maiani, Nucl. Phys. B155, 93(1979); G. Corbo, *ibid.* B212, 99(1983)
M. Jezabek and J.H. Kuhn, Nucl. Phys. B320, 20(1989).
- [4] B. Grinstein, N. Isgur and M.B. Wise, Phys. Rev. lett. 56, 258(1986); N. Isgur, D. Scora, B. Grinstein and M.B. Wise, Phys. Rev. D39, 799(1989).
G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani and G. Martinelli, Nucl. Phys. B208.
- [5] A. Bouzas and D. Zappala, UCLA/94/TEP/10

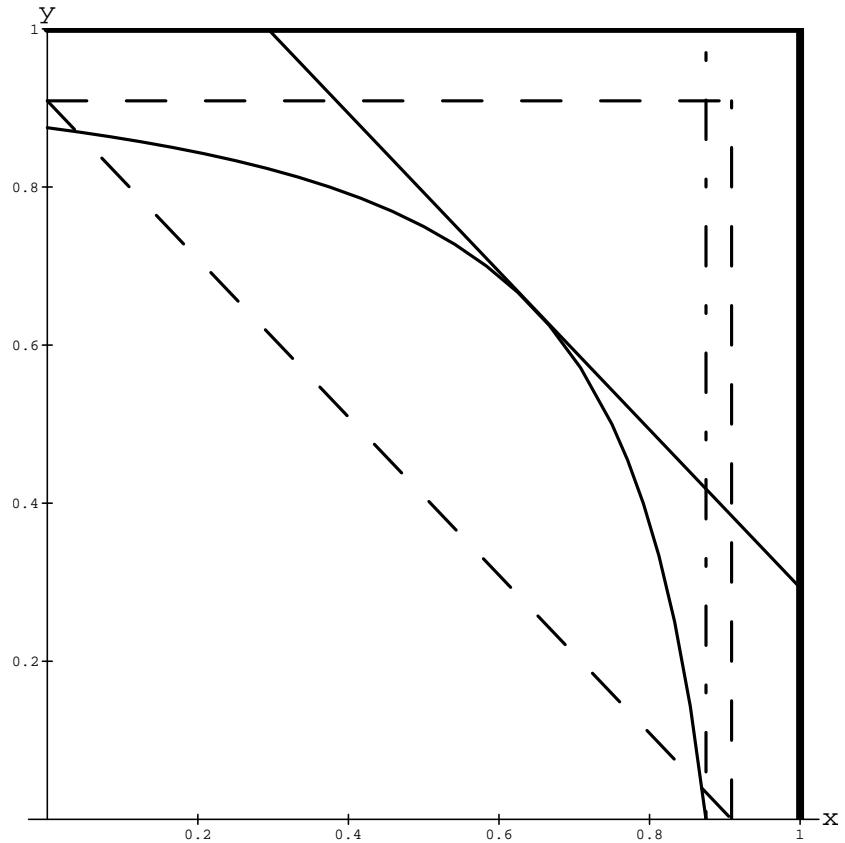


Figure 1: The phase space plot: $x = 2E_l/m_B$, $y = 2E_\nu/m_B$. Lepton and neutrino energy are kinematically allowed inside the square, however, leading order parton model only allows final states inside the dashed triangle, therefore that is where most of the events are expected to be. The conventional method of extracting V_{bu} utilizes the narrow region to the right of the dot-dashed line. Cutting on the total final state hadron energy makes use the region above the solid straight line while still excludes $b \rightarrow c$ decay. Knowing both the lepton and neutrino energy but not the angle between them will allow us to use events above the solid curved line. Below the solid curved line, one can still use the angle to distinguish the two types of decay.